The Journal of Animal and Plant Sciences, Volume 25, issue 3, 2015 p. 713-718
http://www.thejaps.org.pk/docs/Supplementary/v-25-sup-2/67.pdf

AUTOMOTIVE RELATED EXPOSURE TO PARTICULATE AIR POLLUTION IN DEVELOPING COUNTRIES CITIES

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ABSTRACT

Poor urban air quality in developing countriesis a growing public health challenge due to rises in population, industries, urbanization and vehiclesalong with insufficient air quality management. Among the range of air pollutants exposure to particulate matter (PM) is of greatest concern due to its association with chronic obstructive pulmonary diseases. The present study reports traffic related exposure to PM by the roads in Lahore, Pakistan. The measurements of mass and number of PM were carried out by GRIMM analysers (Model 1.108 and Model 1.101) and condensation particle counter (TSI 3781). The heavy metals concentration in PM was determined by Graphite Furnace Atomic Absorption Spectrophotometer (Unicam atomic absorption, Cambridge, UK).The mean hourly average concentration of PM_{10}, $PM_{2.5}$, PM_1 and $PM_{10-2.5}$ at the road siteswas higher during weekdays(305 µg/m^3, 84 µg/m^3, 61 µg/m^3 and 222 µg/m^3, respectively) in comparison to the weekend (136 µg/m^3, 60 µg/m^3, 40 µg/m^3 and 76µg/m^3, respectively). At the background site the levels in the same size fractions were 206µg/m^3, 63µg/m^3, 31µg/m^3, and 143µg/m^3, respectively. Likewise, the number concentration of ultrafine particles was considerably higher at road sites (417,003 #/cm³) than the background(97,300 #/cm³).The concentration of heavy metals in PM decreased in the following order: Si, Al, Zn, Mn, Cu, Ni, Cd, Pb. Overall, the concentration of PM_{10}, $PM_{2.5}$ and toxic metals (Mn, Cd, Ni) was substantially higher than guidelines by the WHO. Furthermore, relatively higher levels of the fine fraction ($PM_{2.5}$ and PM_1) in the background reflect their higher residence time and resultant increased risk of exposure to the wider public beyond that of the vicinity to automotive sources. Everyday commuters, mostly on two and three wheelers as well asthe residential population in urban areas are at an enhanced risk of exposure to high levels of particulate pollution.

Key words: PM, mass concentration, number concentration, heavy metals, urban, developing world.

INTRODUCTION

In recent times poor urban air quality in developing countries has emerged as a significant threat to public health. Substantial growth in the economy, population, industrial sector, urbanization and automotive vehicles has resulted in excessive levels of air pollution in urban areas. There are considerable differences in the concentrations of different air pollutants between developing countries depending on the degree of air quality management systems and socio – economic development status. However, low to middle income countries are worst affected. The World Health Organization (WHO, 2014) has estimated that in 2012 ambient air pollution was responsible for 3.7 million premature deaths and most of these (88%) were in low and middle income countries. Exposure to particulate matter (PM) was held responsible for this large burden of mortality. Exposure to PM_{10} and $PM_{2.5}$ has long been associated with cardiovascular and respiratory diseases (WHO, 2014; Correia*et al*, 2013; Pope *et al*, 2009). In 2013 the WHO's International Agency for Research on Cancer (IARC) concluded that there is sufficient evidence to classify outdoor air pollution, in particular, PM as carcinogenic (Loomis *et al*. 2013).

With reference to urban air quality in Asian cities, a rise in types and number of emission sources of air pollutants due to the intensive growth in industrial sector, urban population and automobile vehicles in the region has resulted in poor air quality with levels many times higher than WHO guidelines and standards in developed countries (Gurjar *et al*, 2008; Hopke *et al*, 2008). A comprehensive review on ambient air pollution and health in developing countries of Asiaby HEI International Scientific Oversight Committee (2010) has concluded that although there has been some improvements in ambient air quality the level of air pollutants in different cities in Asia are well above WHO guidelines. They have also argued that the public health impact of ambient air pollution will grow over periods of time due to demographic and epidemiological transitions and increased prevalence of risk factors.

Pakistan is one the most urbanized countries in South Asia and the state of urban air quality is alarming. The level of different air pollutants in urban centres,

especially, PM are among the highest in the world. A review on state of ambient air quality in Pakistan by Colbeck*et al*, (2010) has reported that it is deteriorating due to rapid rise in emission sources and lack of air quality management capabilities. PM was identified as the most serious air pollutant in the country (Colbeck *et al*, 2010). A recent publication from World Bank (Sanchez-Triana*et al*, 2014)on ambient air pollution in Pakistan has reviewed the concentrations of different air pollutants and their sources in urban centres comprehensively and confirmed that air pollution levels significantly surpass the limits proposed by WHO guidelines and advocate the strengthening of the air quality management to address the crisis of urban air pollution in Pakistan. Emissions from automobile vehicles, industrial facilities and burring of solid waste are main contributors to urban air pollution in Pakistan. All of these sources haveescalated substantially over the last decade. According to the Pakistan Economic Survey 2013-14 air pollution in urban areas of Pakistan is rising due to the enormous increase in number of vehicles, inefficient automotive technology, use of unclean fuels, and uncontrolled emissions from industry, brick kilns and solid waste burning. Among these emissions vehicular sources are the biggest source of air pollution in the country. The number of total vehicles grew by 130.3% over the period of 2001 – 02 to 2012-13. Among these emission from diesel vehicles, motorcycles/scooters and rickshaws contribute most to the deterioration of urban air quality. An increase of 133.8% and 24.4% has been recorded in the number of motorcycles/scooters and rickshaws during 2001 – 2013 (Pakistan Economic Survey, 2013 - 2014).

Hence the urban dwellersare exposed to hazardous levels of air pollutants. Although information on the levels of air pollutants in Pakistan is growing (Sanchez-Triana *et al*, 2014) studies on automotive related exposure are scant (Colbeck *et al*, 2011). The present study reports traffic related exposure to PM by the roads in Lahore – the second largest city of Pakistan by monitoring the mass concentration of PM_{10}, $PM_{2.5}$, PM_1, number concentration of ultrafine particles and heavy metal compositionof airborne PM. This will offer insight into degree of exposure to PM in transport micro environments in urban centres of the developing world.

MATERIALS AND METHODS

The measurements of mass, number and heavy metal concentration of PM were carried out during June – August, 2008 over a period of two weeks at two road sites in Lahore (Multan Road and Out Fall Road). Additionally, measurements of mass concentration were also carried out at a background site (University of Veterinary and Animal Sciences Lahore) simultaneous to road site monitoring during weekdays.The mass concentration of PM_{10}, $PM_{2.5}$ and PM_1 was monitored by two Grimmanalyzers (Model 1.108 and Model 1.101). The number concentration of ultrafine particles was measured with a condensation particle counter (TSI 3781) with an addition of dilution system following Knibbs *et al*, (2007) with some alterations. Model 3781 can detect ultrafine particles down to 6 nm in diameter.

Samples of airborne PM were also collected by an eight stage nonviable impactor (Andersen Impactor). This is a multi-stage, multi-orifice sampler designed to measure the aerodynamic size distribution and mass concentration levels of airborne particles. At 1 CFM (28.3 l/min), the particle fractionation ranges from 9 to 0.4µm aerodynamic diameter.The collection time at each site was between 5 and 8 hours. The medium used to collect the particulate matter was EMP 2000 glass microfiber filter papers (Whatman, England). EPM 2000 has been developed especially for use in high volume air sampling equipment that collects atmospheric particulates and aerosols. It is manufactured from 100% pure borosilicate glass of special purity enabling detailed chemical analysis of trace pollutants to take place with the minimum of interference or background.Field blanks were also kept and analyzed along with the exposed filters

The heavy metals concentration were determined by Graphite Furnace Atomic Absorption Spectrophotometer (Unicam atomic absorption, Cambridge, UK).For extraction each filter was placed in a 50 ml boiling test tubeand 4 ml of 'primar' grade Nitric Acid (70%) was added. Samples in the acid were kept, first, at room temperature for 36 hours, in fume cupboard covered with Decon washed marbles, then digested in a TeckamPTC-2 digestion block. The samples were heated at 50°C for 30 minutes and then at 140ºC for 8 hours. After digestion, the samples were left to cool and stored at room temperature with 5 ml deionized H_2O that was used to wash any residual solution from the test tubes. Acid solutions with the samples were filtered using a syringe filter with glass fibre filter. Filtered samples were poured into a graduated pot and made up to 20 ml with deionized H_2O and analysed using a Graphite Furnace Atomic Absorption Spectrophotometry (Unicam atomic absorption, Cambridge, UK.).

At the road sites sampling was carried out 1meter away from the foot path. For mass and number concentration of PM the data logging interval was one minute and it was later transformed into hourly concentration for the sampling period. These measurements were made at a height of 1 m. The mass concentration of PM was analysed for weekdays and weekend while number concentration was only for the weekdays.

RESULTS AND DISCUSSION

Mass Concentration of PM: The calibration factor for the Grimm analyzerswas determined as 0.80 and data was adjusted accordingly.The temperature and humidity during various days of measurements ranged from 30 – 35C° and 50 – 70%, respectively. Table 1 presents the summary of results for different size fractions of PM over the period of monitoring. During the weekdays (Monday - Friday) the mean hourly average concentration of PM_{10}, $PM_{2.5}$, PM_1 and $PM_{10} - PM_{2.5}$at the road sites was 305µg/m^3, 84µg/m^3, 61µg/m^3 and 222µg/m^3, respectively (Table 1). The coarse size fraction was particularly large but also exhibited a wide variation. Comparison of these concentrations with levels reported by the road sides in an earlier study carried out in Lahore by Colbeck *et al*, (2011) revealed that the average levels of $PM_{2.5}$ and PM_1 between two measurement campaigns were comparable. However, PM_{10} was lower during this campaign. Similarly the mean concentrations of $PM_{2.5}$ and PM1during weekdays in this study were in agreement with Alam *et al*, (2011). They reported average concentration of 91µg/m^3 and 68µg/m^3 for $PM_{2.5}$ and PM_1 fromLahore. Again the levels of PM_{10} in their study were lower than the current study. These variations in PM_{10} are probably due to differential sources of coarse size particles at each sites and low residence time of PM_{10}, as the sampling by Alam *et al*, (2011) was carried out at roof of a building in a residential area of Lahore.

In contrast, during the weekend (Saturday - Sunday), the average concentration of PM_{10}, $PM_{2.5}$, PM_1 and $PM_{10} – PM_{2.5}$ showed a substantial fall. The biggest drop was seen in coarse size fraction and levels of PM_{10} were 136µg/m^3 in comparison to 305µg/m^3 during weekdays. The concentration of $PM_{2.5}$ and PM_1 dropped to 60µg/m^3 and 40µg/m^3, respectively (Table 1). This suggests that a considerable amount of particulate matter is in coarse size fraction and resuspension of road dust during the traffic movement is probably the principal contributor in mass concentration. The hourly average concentration of PM_{10}, $PM_{2.5}$, PM_1 and $PM_{10} – PM_{2.5}$ at a background site (University of Veterinary and Animal Sciences, Lahore) during the week days was 206µg/m^3, 63µg/m^3, 31µg/m^3, and 143µg/m^3, respectively. The concentration of $PM_{10}$and $PM_{2.5}$ at the background site was comparable to Colbeck *et al*. (2011).

Table 1.Hourly average mass concentration of particulate matter (µg/m^3) by the road sites during weekdays, weekends and at background site in Lahore (9am – 11 pm)

	PM_{10}	$PM_{2.5}$	PM_1	PM_{10} - $PM_{2.5}$
Weekdays				
Ave. (µg/m^3)	305	84	61	222
Max. (µg/m^3)	534	107	85	440
Min. (µg/m^3)	187	48	35	126
Std.Dev. (µg/m^3)	98	19	18	92
Weekends				
Ave. (µg/m^3)	136	60	40	76
Max. (µg/m^3)	155	66	46	95
Min. (µg/m^3)	122	52	34	65
Std.Dev. (µg/m^3)	12	6	5	10
Background				
Ave. (µg/m^3)	206	63	31	143
Max. (µg/m^3)	259	71	32	187
Min. (µg/m^3)	160	56	30	105
Std.Dev. (µg/m^3)	42	6	1	36

Ave. (Average), Max. (Maximum), Min. (Minimum), Std. Dev. (Standard Deviation).

Most of the studies carried out in the region have only reported PM_{10} concentrations. The levels in this study are in good agreement with those in urban areas of neighbouring countries. For example, Laakso *et al*. (2006) reported that the average concentration of PM_{10} in Delhi was 360µg/m^3. Similarly, Mönkkönen *et al*. (2004) found that mean monthly averages of PM_{10} in Delhi were in the range of 175 – 422µg/m^3. However these are many times higher than WHO guidelines. The analysis of ambient air quality by Sanchez-Triana *et al*. (2014) has demonstrated that concentrations ofPM_{10} frequently surpass 200µg/m^3 in Pakistan and they reported average values of $PM_{2.5}$ µg/m^3 in Lahore as 143 µg/m^3- higher than our study.

Number Concentration of Ultrafine Particles: The mean hourly average number concentration during weekdays at road sites was 417003 #/cm³ with a maximum and minimum of 659068 (#/cm³)and 111365(#/cm³), respectively. On the other hand, at the background site (University of Veterinary and Animal Sciences, Lahore) the mean hourly mean concentration

ranged from 87359 - 104859 #/cm³ with a mean value of 97300 #/cm³ (Table 2). These results show a significant difference between number concentrations at the road site and background highlighting the contribution from automobile exhaust. Furthermore the large standard deviation values at road sites reflect the differences in traffic density over the time of day, whereas, concentrations were more stable at background site.

Table 2. Hourly average number concentration (#/cm³) of ultrafine particlesat the road sites and at background site during weekdays in Lahore. (9am – 11 pm)

	Road Sites	Background Site
Ave. (#/cm³)	417003	97300
Max. (#/cm³)	659068	104859
Min. (#/cm³)	111365	87359
St Dev. (#/cm³)	206549	8990

Ave. (Average), Max. (Maximum), Min. (Minimum), St Dev. (Standard Deviation).

There are only few studies on number concentration of ultrafine particles in developing countries and direct comparison cannot be made with studies reported from the developed world. The concentrations by the roads are higher than the levels reported by Mönkkönen *et al.* (2004) and Laakso *et al.* (2006) from Delhi, India. However these studies were carried out at an urban background site and the number concentrations for background site during this study were comparable to them. Mönkkönen *et al.* (2004) reported the average diurnal variation of particle number concentration at an urban background site in New Delhi, India during March, April, May, June, October and November, 2002. The diurnal hourly mean number concentration (> 10 nm) varied from 16,000 #/cm³ to 130,000 #/cm³. Laakso *et al*. (2006) found that the average number concentration (3 – 800 nm) in New Delhi, was 63, 000 #/cm^3.Overall, the levels of particulate matter were almost double during the weekdays than weekends. This suggests a significant contribution from road traffic. A large fraction of particulate matter was in the size range PM_{10} – $PM_{2.5}$. Similarly, the number concentration was many times higher by the road sites than the background site. Although the concentrations of PM at the background site were lower than road sites, their levels were substantially higher than the guideline value by the WHO and this might have severe implications in terms of risk of PM exposure to wider population.

Heavy Metals in AirborneParticulate Matter: The heavy metal composition of particulate matter at the road sites in Lahore is shown in Fig. 1. The concentration of heavy metals had the following decreasing order: Si (19.11 µg/m^3), Al (11.54 µg/m^3), Zn (1.78 µg/m^3), Mn (0.64 µg/m^3), Cu (0.37 µg/m^3), Ni (167.42 ng/m^3), Cd (92.93 ng/m^3), Pb(51.88 ng/m^3). The average airborne metal concentration can be compared with guideline values proposed by various agencies. During the present study, the concentration of Pb was within the guideline value of the WHO (0.5 µg/m^3) but the levels of Mn were higher than the WHO guideline value of 0.15 µg/m^3 (WHO, 2002). The concentrations of Cd and Ni were in excess of limit (Cd – 5ng/m^3; Ni – 10-50 ng/m^3) proposed by European Commission (European Commission, 2000).

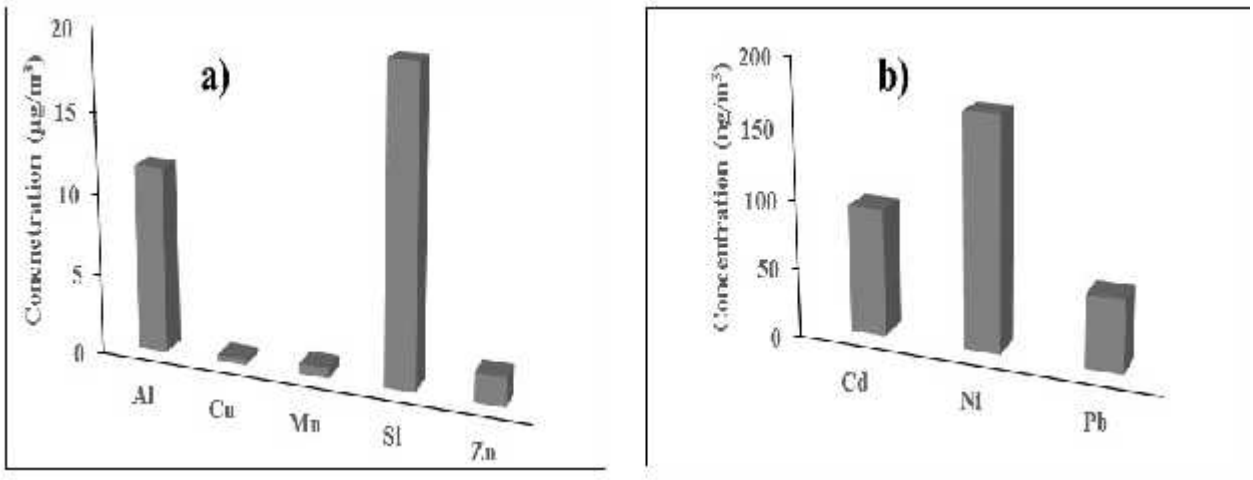

Fig. 1 The heavy metal composition of airborne particulate matter at road sites in Lahore. a)µg/m^{3}b)ng/m^3

Shah and Shaheen (2008) reported the annual levels of heavy metals from Islamabad, where concentrations of Mn, Cd and Ni were lower than in the present study, while Zn and Pb were higher and Cu had

roughly the same levels. The levels of Pb, Zn and As were far lower in the present study than those reported by Farhana and Husain (2006) from Lahore and only Cd levels were comparable. This was probably due to differences in sampling periods and locations. The study by Farhana and Husain (2006) was carried out in winter with fog episodes and atmospheric stagnation was identified as the cause of periodic high concentrations of the pollutants. In Bangladesh, according to Begum *et al*, (2006), the levels of Pb (124 ng/m^3) were higher than in the present study, while Zn, Cu and Ni were lower than in the present study. However, similarly to the present study, they also found the highest contribution to be from Si (4.45 µg/m^3) and Al (2.14 µg/m^3). Table 3 compares current study with earlier studies reported from Lahore. In comparison to Schneidemesser *et al*. (2010) the levels of Al, Mn, Cu, Cd and Ni were higher while Zn and Pb were lower in the current study. The study by Alam *et al*. (2011) reported higher concentrations of Cu, Pb and Ni than that of current study.

Table 3. Comparison of heavy metals in PM reported fromurban air of Lahore

Heavy Metals	**Urban Sites at Lahore**		
	Alam*et al*. (2011)	Schneidemesser*et al*. (2010)	Currentstudy
Al (µg/m^3)	9.52	8.4	11.54
Cu(µg/m^3)	0.66	0.073	0.37
Mn (µg/m^3)	0.205	0.3	0.64
Si (µg/m^3)	3.32	-	19.11
Zn (µg/m^3)	1.64	11	1.78
Pb (µg/m^3)	1.10	4.4	0.051
Cd (ng/m^3)	59	77	92.93
Ni (ng/m^3)	360	18	167.42

The observed differences during different campaigns are perhaps due to differences in sampling location and related microclimates at each site. The present study revealed lower levels of Pb and this is probably due to removal of lead from gasoline. However, given the pace of industrialization and motorization, a rise in the airborne concentrations of other heavy metals is very likely.

Conclusion: The present study examined the mass concentration of PM_{10}, $PM_{2.5}$, PM_1, number concentration of ultrafine particles and heavy metal composition of airborne PM by road sides in Lahore with a view to highlight traffic related exposure to PM in developing countries. In general both mass and number concentration of particles was higher at road sides than the background site. Nonetheless, the levels of PM_{10} and $PM_{2.5}$ were many times higher than WHO guidelines at both sites. Additionally concentrations of toxic heavy metals (Mn, Cd, Ni) were also in excess of safe limits proposed by the WHO and European Commission.Higher concentrations of PM in all the size fraction at the background site in the city reflect long term exposure, in particular to fine particle ($PM_{2.5}$ and PM_1) to the wider public beyond that of road sides. In general, the causes of poor urban air quality in developing countries are similar and have been experienced by the developed world as well during 20th century. Intervention strategies are well known and there are range of example interventions proposed byinternationalorganizations (e.g. WHO) but there is a dire need to accept urban air pollution as one the biggest public health challenges in the developing world at policy and practice level. With reference to Pakistan the recent publication by Sanchez-Triana *et al.* (2014) has a wealth of information on the existing state of air quality management and pragmatic interventions to improve urban air quality in the country. Given the ever rising number and types of emission sources of urban air pollution, absence of targeted interventions would lead to further deterioration of urban air quality and resultant higher burden of disease and cost to economy.

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